
Efficiency of rotary nickel–titanium FlexMaster instruments compared with stainless steel hand K-Flexofile – Part 1. Shaping ability in simulated curved canals

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Abstract

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Aim The purpose of this study was to compare the shaping ability of FlexMaster rotary nickel–titanium instruments with stainless steel hand K-Flexofiles. This part of the two-part report describes the efficiency of these two instruments in simulated curved root canals.

Methodology Simulated 28°- and 35°-curved canals were prepared by the FlexMaster instruments with a rotational speed of 250 rpm using a crown-down preparation technique, and by the K-Flexofiles using a reaming motion ($n = 24$ canals in each case). All canals were prepared up to size 35. The pre- and post-instrumentation images were recorded and assessment of the canal shape was completed with a computer image analysis program. The material removal was measured at 20 measuring points, beginning 1 mm away from the apex.

Incidence of canal aberrations, preparation time, changes of working length and instrument failures were also recorded.

Results In comparison with stainless steel K-Flexofiles, the rotary FlexMaster instruments achieved better canal geometry, showed less canal transportation and created fewer canal aberrations in both the canal types. Two FlexMaster instruments were separated, and 15 FlexMaster instruments and 11 K-Flexofiles were permanently deformed during preparation. However, these differences were not significant ($P > 0.05$). Between both the canal types, FlexMaster was significantly faster ($P < 0.001$) than K-Flexofiles. Both instruments maintained a good working distance.

Conclusions FlexMaster instruments prepared curved canals rapidly, and with minimal transportation towards the outer aspect of the curve.

Keywords: canal transportation, curved root canals, nickel–titanium, resin blocks, root-canal preparation, rotary instruments.

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Introduction

The unique metallurgical properties of nickel–titanium have made it possible to develop relatively safe rotary instruments. All the new systems incorporate instruments with a taper greater than the ISO standard 0.02 design; indeed rotary nickel–titanium instruments are available with tapers ranging from 0.04 to 0.12

(Thompson & Dummer 1997a). These greater taper instruments have been introduced to improve the relatively low cutting efficiency (Tepel *et al.* 1995) of nickel–titanium instruments, to reduce the incidence of instrument failures and to enhance canal shape.

Recently, there have been many reports on the effectiveness of rotary nickel–titanium instruments while shaping either simulated root canals in resin blocks (Tepel 1997, Thompson & Dummer 1997a,b, Baumann & Roth 1999, Schäfer & Fritzenschaft 1999, Kum *et al.* 2000, Thompson & Dummer 2000a) or extracted human teeth with curved root canals (Kosa *et al.* 1999, Jardine

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& Gulabivala 2000). These studies corroborate the ability of rotary nickel–titanium instruments to maintain the shape of even severely-curved canals. Furthermore, in most of these studies, it has been pointed out that canal enlargement was significantly faster with rotary nickel–titanium instruments compared to the hand preparation (Thompson & Dummer 1997a,b,c, Schäfer & Fritzenschaft 1999, Kum *et al.* 2000, Thompson & Dummer 2000a). However, other aspects of the root-canal preparation with rotary nickel–titanium instruments, such as their increased cost and their susceptibility to corrosion under clinical conditions (Thompson 2000) are controversial (Schäfer 1998, Thompson 2000).

To date, little information on the mechanical properties and shaping ability of nickel–titanium FlexMaster instruments is available. The FlexMaster instruments are made of 55-nitinol (Lohmann *in press*), with cutting edges machined into a round blank, resulting in a convex cross-section that is characterized by three equally spaced cutting edges, which are very similar to K-type blades (Fig. 1). The instrument does not have radial lands or U-shaped blades. The FlexMaster instruments have flattened, non-cutting tips and a rounded transitional angle (Fig. 2). Thirteen FlexMaster instruments are

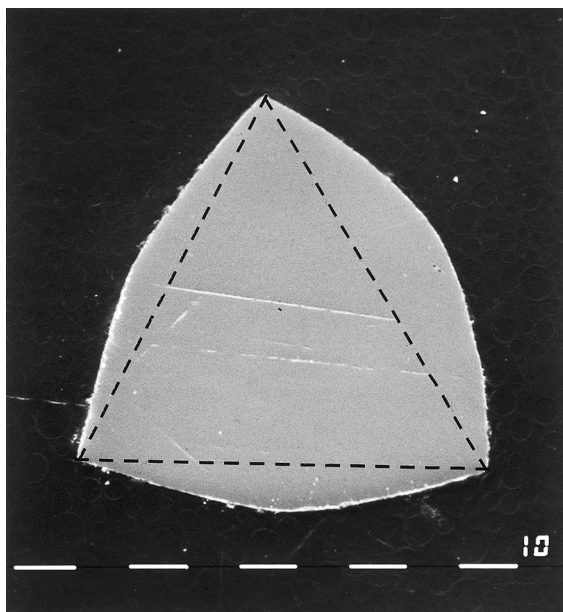


Figure 1 Scanning electron microscope image of the cross-section of a FlexMaster instrument (0.06 taper size 30; original magnification 80 \times) showing three equally spaced K-type cutting edges. The cross-section of a K-type file is indicated by dotted lines.

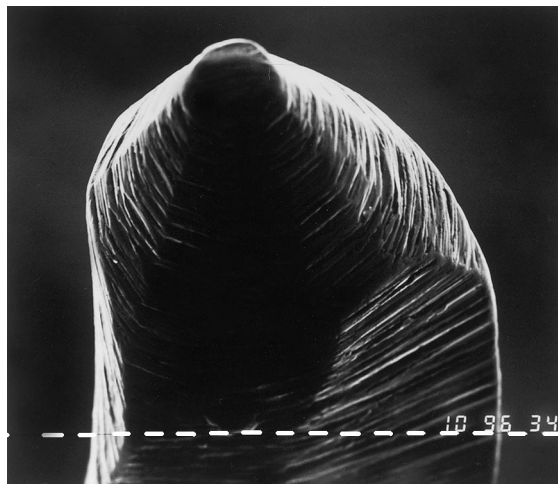


Figure 2 Scanning electron microscope images of the tip region of FlexMaster instruments showing a non-cutting, flattened tip with rounded transitional angles (0.06 taper size 20; original magnification 320 \times).

available: sizes 20, 25 and 30 have three different tapers (0.02, 0.04 and 0.06), size 35 has two different tapers (0.02 and 0.06) and sizes 40 and 45 have only a 0.02 taper. The manufacturer recommends that root canals be enlarged with these instruments using the crown-down technique. Depending on the clinical situation, all instruments are not needed for canal enlargement and the instrumentation sequence can be modified according to the degree of curvature and the diameter of the root canal to be prepared. In curved and/or narrow canals, the instruments with greater tapers are designed to initially enlarge the coronal and middle portion of the canal, whilst the 0.02-tapered instruments are used to finish the apical area and to merge the apical and coronal preparations.

The purpose of this study was to compare automated FlexMaster rotary nickel–titanium instruments with stainless steel hand K-Flexofiles (Dentsply Maillefer, Ballaigues, Switzerland) used in a reaming motion during the shaping of simulated curved root canals in resin blocks.

Materials and methods

Simulated canals

Simulated canals made of clear polyester resin (Viapal uP 004/64, Vianova Resins, Hamburg, Germany) with coloured canal walls were used to assess instrumentation. The degree of curvature was either 28° or 35°. The

diameter and the taper of all simulated canals were equivalent to an ISO standard size 15 root-canal instrument. The 28° canals were 13-mm long, the straight part being 5.5 mm and the curved part 7.5 mm. The curvature was defined mathematically with a radius of 7.5 mm resulting in an angle of 28° according to the Schneider method (Schneider 1971). The 35° canals were 13-mm long, the straight part being 5 mm and the curved part 8 mm. The radius of the curvature was 6.5 mm.

Preparation of simulated canals

The simulated canals were prepared either with the FlexMaster rotary nickel–titanium instruments or the stainless steel hand K-Flexofiles. The transparent blocks were covered with adhesive tape during the preparation phase. All instruments were used to enlarge two canals only. Prior to use, each instrument was coated with glycerine to act as a lubricant, and copious irrigation with water was performed repeatedly after the use of each instrument. All canals were enlarged by an operator experienced in both manual instrumentation with stainless steel K-Flexofiles and automated preparation with FlexMaster instruments. Measurement of the canals were carried out by a second examiner who was blinded with respect to all the experimental groups. A randomly laid down sequence was used to avoid bias towards one of the two instrumentation techniques, that is rotary instrumentation with the nickel–titanium FlexMaster instruments or manual reaming with the stainless steel K-Flexofiles. Only six resin blocks (three with 28° curves and three with 35° curves) were instrumented at a time to minimize operator fatigue and familiarity. These six resin blocks were defined as a set. The order of use of the two instrument types within a set was rotated.

All canals were enlarged to an apical size 35. The following instrumentation sequences were used with the different instruments:

Group A: FlexMaster instruments were set into permanent rotation (250 rpm) with a 8 : 1 reduction handpiece (Type 5059, Nouvag, Goldach, Switzerland) powered by a torque-limited electric motor (TCM Endo 2, Nouvag, Konstanz, Germany) using torque setting 2, which is as stated by the manufacturer to be equivalent to a torque limitation of 1.5–1.7 Ncm. Instrumentation was completed in a crown-down manner according to the manufacturer's instructions using a gentle in-and-out motion. Instruments were withdrawn when resistance was felt and changed for the next instrument. The

preparation sequence was slightly modified from that recommended by the manufacturer, because in a pilot study the following instrumentation sequence allowed preparation of the different canals without difficulties:

- 1 A 0.06 taper size 20 instrument was used to 7 mm.
- 2 A 0.04 taper size 30 instrument was used to 9 mm.
- 3 A 0.04 taper size 25 instrument was used to 11 mm.
- 4 A 0.04 taper size 20 instrument was used to 13 mm, the full length of the canal.
- 5 A 0.02 taper size 25 instrument was used to 13 mm, the full length of the canal.
- 6 A 0.02 taper size 30 instrument was used to 13 mm, the full length of the canal.
- 7 A 0.02 taper size 35 instrument was used to 13 mm, the full length of the canal.

Once, the instrument had negotiated to the end of the canal and had rotated freely, it was removed.

Group B: hand instrumentation with the K-Flexofile stainless steel instruments with non-cutting tips was performed using a reaming motion. All canals were sequentially prepared from size 15 up to 35 without pre-bending the instruments, which were used to 13 mm, the full length of the canal.

In each of these two test groups, 24 canals with 28° and 24 canals with 35° curves were enlarged. Thus, a total of 96 canals were prepared.

Assessment of canal preparation and analysis of data

The time for canal preparation was recorded, and the total active instrumentation, instrument changes within the described instrumentation sequence and irrigation was included. Changes of working length were determined by subtracting the final length (measured to the nearest 0.5 mm) of each canal after preparation from the original length (13 mm). The preparation time and the change of working length were statistically analyzed using the Mann–Whitney *U*-test at a significance level of $P < 0.05$. The number of fractured and permanently deformed instruments during enlargement was also recorded. A χ^2 -test was used to determine whether there were significant differences between the two instruments concerning the instrument failure and the deformation of instruments.

The assessment of preparation shape was carried out with the computer program Image 1.41 (National Institutes of Health public domain program). Therefore, the pre- and post-instrumentation canal shapes were taken in a standardized manner and magnified 40 times by means of a charged coupled device (CCD) camera (SSC-M370CE, Sony Corporation, Tokyo, Japan)

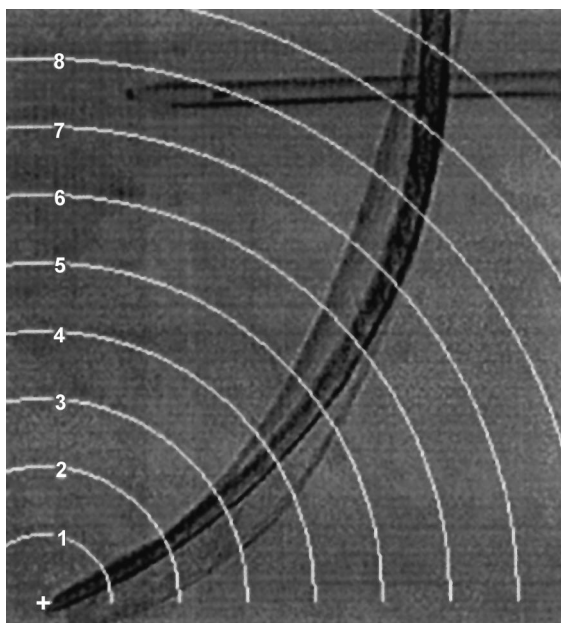


Figure 3 Composite print of a simulated 35°-curved canal after instrumentation with stainless steel K-Flexofiles (white region) and before preparation (black region). The 20 positions of measurement are outlined by the concentric circles.

and stored in the computer (Macintosh Quadra 660 AV, Apple Computer, Ismaning, Germany). Thereafter, a composite image of the pre- and post-instrumentation images was produced and superimposed (Fig. 3). The amount of resin removed, e.g. the difference between the canal configuration before and after instrumentation was determined both for the inner and the outer side of the curvature in 1 mm steps using the Image 1.41 program. The amount of resin substance removed in all canals was measured one-dimensionally with a precision of ± 0.01 mm. The first measuring point was 1 mm away from the apical ending of the canal, the last measuring point was 10 mm from the apical ending, resulting in 10 measuring points at the outer and 10 points at the inner side of the canal, and thus, in a total of 20 measuring points (Schäfer *et al.* 1995, Tepel 1997). All measurements were made at right angles to the surface of the canal. The data were analyzed by the Mann–Whitney *U*-test, because for some measuring points the data was not distributed normally according to the Kolmogorov–Smirnov test.

Furthermore, based on the superimposition of pre- and postoperative images, assessments were made according to the presence of different types of canal

aberrations, such as apical zip associated with elbow, ledge, and perforation. These different types of canal aberration were defined according to the detailed descriptions published recently (Thompson & Dummer 2000b).

Results

During the preparation of the 96 canals, a total of two instruments separated. Therefore, the following results were based on the remaining 94 canals. Two canals with 35° curves were excluded.

Instrument failure

Table 1 details the number of deformations and fractures of instruments which occurred during the study. Independent of the curvature of the canals, none of the stainless steel K-Flexofiles separated. In the 28°-curved canals, no fracture of the FlexMaster instruments occurred but in the 35°-curved canals two nickel–titanium instruments (both 0.04 taper size 20, and used for the second canal) separated. The number of separated instruments ($\chi^2 = 0.511$, $P = 0.478$) and the number of permanently deformed instruments ($\chi^2 = 0.475$, $P = 0.492$) was not significantly different between the instrument types.

Preparation time

The mean time taken to prepare the canals with the different instruments is shown in Table 2. Independent

Table 1 Number of fractured and permanently deformed instruments

Instrument	28°-Curved canals		35°-Curved canals	
	Fractured	Deformed	Fractured	Deformed
FlexMaster	0	7	2	8
K-Flexofile	0	7	0	4

Table 2 Mean preparation time (min) and SD with the two different instruments

Instrument	28°-Curved canals		35°-Curved canals	
	Mean	SD	Mean	SD
FlexMaster	4.73	0.54	4.55	0.43
K-Flexofile	5.39	0.46	5.63	0.72

Table 3 Mean loss of working length (mm) and SD with the two different instruments

Instrument	28° -Curved canals		35° -Curved canals	
	Mean	SD	Mean	SD
FlexMaster	0.31	0.35	0.31	0.28
K-Flexofile	0.29	0.36	0.39	0.41

of the curvature of the canals, the shortest mean preparation time was recorded when FlexMaster instruments were used. Both in 28°- and 35°-curved canals, FlexMaster was significantly faster than K-Flexofiles ($P < 0.001$).

Change of working length

All canals remained patent following instrumentation, thus, none of the canals became blocked with resin shavings. None of the canals showed overextension of preparation, whereas a loss of working distance was found in several canals.

The mean loss of working length which occurred with the different instruments is listed in Table 3. The differences between the two instrument types were not statistically significant, in either the 28°-curved ($P = 0.828$) or 35°-curved canals ($P = 0.628$).

Table 4 Incidence of canal aberrations by instrument types

Aberration type	28° -Curved canals		35° -Curved canals	
	FlexMaster	K-Flexofile	FlexMaster	K-Flexofile
Zip/elbow	1	4	2	5
Ledge	2	4	2	4
Perforation	0	0	0	1

χ^2 -test, no significant differences ($P > 0.05$).

Canal shapes

The results concerning the assessment of canal aberrations are summarized in Table 4. With respect to the different types of aberrations evaluated, both in canals with 28° and with 35° curves, there were no significant differences between the two instrument types (χ^2 -test, $P > 0.05$), but, more zips and ledges were created with K-Flexofiles. Only one perforation was created by K-Flexofile in a 35°-curved canal.

On average, in the canals with 28° curves, FlexMaster instruments removed material more evenly on the outer, as well as on the inner side of curvature (Fig. 4a). With the exception of three measuring points, significant differences ($P < 0.05$) occurred between resin removal achieved with the two different instruments (Table 5). The canals prepared with FlexMaster instruments remained better centred compared with those enlarged with K-Flexofiles (Fig. 4).

DropBooks

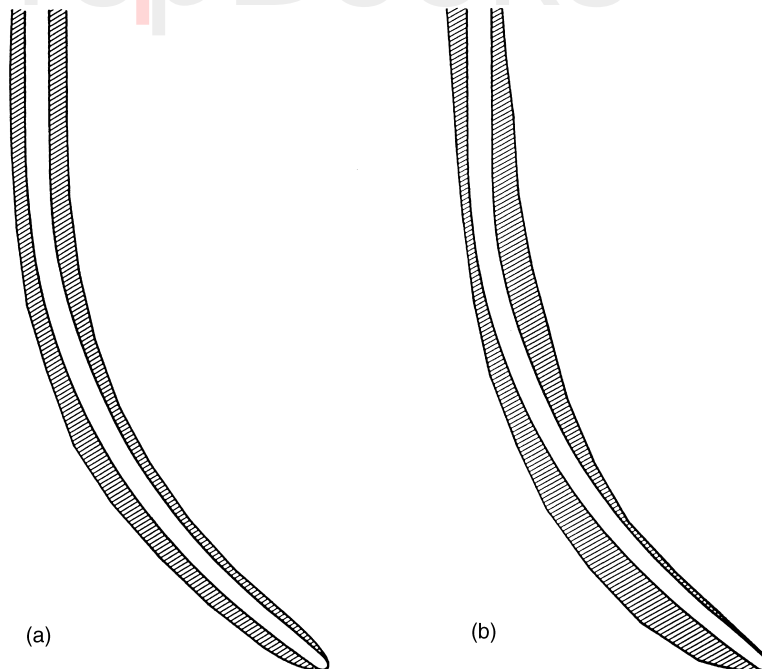


Figure 4 Mean changes in the canal shape of 28°-curved canals as the result of instrumentation with (a) rotary nickel-titanium FlexMaster instruments and (b) stainless steel hand K-Flexofiles ($n = 24$ canals in each case).

Table 5 Mean material removed (mm) and SD at the different measuring points after instrumentation of simulated 28°-curved canals

	Inner canal wall (millimetres from the apex)										Outer canal wall (millimetres from the apex)									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
FlexMaster																				
Mean	0.04	0.05	0.06	0.08	0.10	0.14	0.19	0.23	0.22	0.19	0.15	0.18	0.21	0.24	0.25	0.23	0.17	0.12	0.09	0.10
SD	0.02	0.03	0.04	0.05	0.07	0.08	0.09	0.10	0.09	0.10	0.04	0.05	0.05	0.07	0.07	0.08	0.08	0.09	0.07	0.08
K-Flexofile																				
Mean	0.01	0.01	0.03	0.13	0.24	0.34	0.38	0.29	0.26	0.13	0.39	0.44	0.43	0.38	0.27	0.16	0.09	0.06	0.07	0.15
SD	0.01	0.01	0.03	0.07	0.07	0.07	0.07	0.11	0.08	0.08	0.07	0.06	0.06	0.08	0.09	0.08	0.05	0.02	0.02	0.06
P-value	***	***	*	*	***	***	***	***	0.076	*	***	***	***	***	0.599	*	**	*	0.270	*

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

In the canals with 35° curves, the FlexMaster instruments removed more material on the outer side of the curvature (Fig. 5a). On average, only limited material removal occurred at the inner side of the curvature in the apical part of the canals (Table 6). This effect was not significantly different compared with the material removal achieved with K-Flexofiles at these measuring points ($P > 0.05$). Canals shaped with K-Flexofiles had material removed mainly in the last 1–4 mm along the outer side of the curvature, resulting in moderate outer widening of the canal (Fig. 5b). In general, the FlexMaster instruments showed a more

centred enlargement compared with the K-Flexofiles (Fig. 5).

Discussion

The purpose of this study was to compare the relative efficiency and shaping ability of rotary FlexMaster nickel–titanium instruments with stainless steel hand K-Flexofiles. K-Flexofiles were chosen as controls, because it is well-known that out of all hand instruments used in a rotary motion, these instruments displayed the greatest cutting efficiency (Tepel *et al.* 1995) and most ideal shape

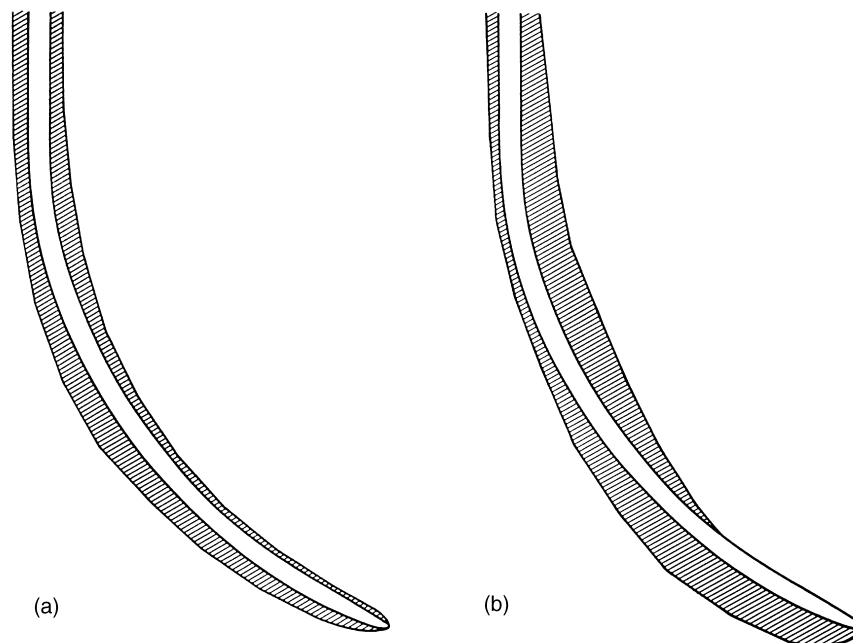
**Figure 5** Mean changes in the canal shape of 35°-curved canals as the result of instrumentation with (a) rotary nickel–titanium FlexMaster instruments and (b) stainless steel hand K-Flexofiles ($n = 24$ canals in each case).

Table 6 Mean material removed (mm) and SD at the different measuring points after instrumentation of simulated 35°-curved canals

	Inner canal wall (millimetres from the apex)										Outer canal wall (millimetres from the apex)									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
FlexMaster																				
Mean	0.01	0.01	0.03	0.04	0.07	0.12	0.18	0.23	0.16	0.13	0.16	0.21	0.25	0.30	0.34	0.32	0.23	0.16	0.14	0.16
SD	0.01	0.01	0.03	0.04	0.06	0.09	0.11	0.10	0.10	0.10	0.05	0.05	0.06	0.06	0.05	0.08	0.07	0.09	0.08	0.10
K-Flexofile																				
Mean	0	0	0.05	0.21	0.34	0.45	0.51	0.48	0.36	0.22	0.45	0.51	0.50	0.41	0.28	0.14	0.07	0.05	0.06	0.12
SD	0.01	0.01	0.04	0.08	0.10	0.10	0.11	0.12	0.11	0.12	0.08	0.05	0.06	0.07	0.09	0.09	0.07	0.05	0.05	0.11
P-value	0.291	0.212	0.149	***	***	***	***	***	***	*	***	***	***	***	*	***	***	***	**	0.103

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

(Al-Omari *et al.* 1992, Schäfer *et al.* 1995). Moreover, like the FlexMaster instruments (Fig. 2) the K-Flexofiles also possess a non-cutting tip without transition angle (Schäfer *et al.* 1995, Bishop & Dummer 1997). Because there is no evidence in the literature to suggest that K-Flexofiles are better used in a linear or rotational working motion (Bishop & Dummer 1997), these instruments were used in a reaming motion as the present K-file has a triangular cross-section. Indeed, several authors have pointed out that the K-files used in a reaming working motion were more efficient and their use resulted in less canal transportation compared to the K-type instruments in a filing motion (Jungmann *et al.* 1975, Roane *et al.* 1985).

The present study described the shaping abilities of the instruments under strictly controlled laboratory conditions, using clear resin blocks. The use of simulated canals in resin blocks does not reflect the action of the instruments in root canals of real teeth. However, resin blocks allow a direct comparison of the shaping ability of different instruments (Schäfer *et al.* 1995). A major drawback of using rotary instruments in resin blocks is the heat generated, which may soften the resin material (Kum *et al.* 2000) and lead to binding of cutting blades, and separation of the instrument (Thompson & Dummer 1997c, Baumann & Roth 1999). Thus, owing to the nature of the resin, care should be exercised in the extrapolation of the present results on failure of the use of the FlexMaster instruments in real root canals, where dentine is involved (Thompson & Dummer 1997c).

In comparison with the stainless steel K-Flexofiles, rotary FlexMaster instruments achieved better canal geometry, showed less canal transportation and straightening (Figs 4 and 5), and created fewer canal aberrations (Table 4), both in canals with 28° and 35° curves. The ability of rotary nickel–titanium instruments to maintain the original shape of curved canals has been confirmed by several studies (Thompson & Dummer 1997a,b,c,d, Baumann & Roth 1999, Kum *et al.* 2000).

However, similar to other rotary nickel–titanium instruments the FlexMaster instruments created a slight canal transportation toward the outer aspect of the curvature in the apical region of the canals, especially in those having 35° curves (Thompson & Dummer 1997d, Thompson & Dummer 1998, Baumann & Roth 1999, Thompson & Dummer 2000b). This canal transportation may be owing to root-canal preparation with instruments of greater taper, because these are stiffer compared with those of ISO taper (Kum *et al.* 2000, Thompson & Dummer 2000b). In contrast, canals enlarged manually with K-Flexofiles showed a more marked transportation toward the outer aspect of the curves and, although not statistically significant (Table 4), a higher incidence of canal aberrations (Al-Omari *et al.* 1992, Schäfer *et al.* 1995, Bishop & Dummer 1997, Kum *et al.* 2000).

In several studies, the shaping ability of different rotary nickel–titanium instruments and flexible stainless steel hand K-files have been compared, using either simulated canals in resin blocks or extracted human teeth. Kosa *et al.* (1999) compared canal transportation in moderately curved mesial roots of mandibular molars using rotary ProFile Series 29 instruments and stainless steel Flex-R files in a contra-angle handpiece. According to their results, there was no difference in the magnitude of absolute transportation between these systems. Luiten *et al.* (1995) and Esposito & Cunningham (1995) found no significant differences between NiTiMatic rotary nickel–titanium instruments and stainless steel K-Flex hand files. However, the results of two more recently published studies (Schäfer & Fritzenschaft 1999, Kum *et al.* 2000) corroborate the findings of the present investigation, in that in severely curved simulated canals the use of rotary nickel–titanium instruments resulted in less canal transportation, fewer canal aberrations, less instrumentation time and better maintenance of working distance compared with stainless steel K-Flexofiles.

In the present study, none of the canals became blocked with resin shavings and none of the canals showed over-extension of preparation. Thus, the only changes of working length was a decrease of working distance. In general, it was possible with both types of instruments to control the working distance adequately (Table 3). This finding is in agreement with the observations of several other studies, in which only small mean changes in working distance occurred with rotary nickel-titanium instruments (Kum *et al.* 2000, Thompson & Dummer 2000a). On the whole, it is questionable whether the small changes of working length observed in the present study may have any clinical significance. These changes may be owing to minor canal straightening during canal enlargement or the lack of length control by the operator (Thompson & Dummer 2000a).

The mean time for the canal preparation was recorded and instrument changes within the described instrumentation sequences were included. Both, in the 28°- and 35°-curved canals, the FlexMaster instruments were significantly faster than the hand preparation with K-Flexofiles (Table 2). This is in agreement with the findings of several authors that instrumentation times with rotary nickel-titanium instruments are substantially faster than with stainless steel hand instruments (Thompson & Dummer 1997a,b,c, Kum *et al.* 2000, Thompson & Dummer 2000a).

During the present study, no fractures occurred with K-Flexofiles, whereas two FlexMaster instruments separated, both in canals with 35° curves. It is worth emphasizing, that these both were 0.04 taper size 20 instruments and were used for the instrumentation of the second canal. To date, no data are available on the torsional properties of the FlexMaster instruments, therefore, no explanation can be given why this particular instrument was susceptible to separation. Related to the total number of FlexMaster instruments used a fracture rate of approximately 1% (2 out of 168 the FlexMaster instruments used when all instruments were used to enlarge two canals) resulted. This separation rate is in agreement with previously reported fracture rates of newer rotary nickel-titanium instruments (Thompson & Dummer 1997a, Baumann & Roth 1999, Kum *et al.* 2000, Thompson & Dummer 2000a).

Conclusions

In conclusion, within the limitations of the present study, the FlexMaster instruments prepared curved canals rapidly, without substantial change in working length, only with few canal aberrations and minimal

transportation towards the outer aspect of the curve. Nevertheless, further studies will be needed to evaluate three-dimensional analysis of the prepared canal in order to assess smoothness, flow characteristics and taper of the enlarged canals.

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